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ELECTRONIC PROGRESS

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RAYTHEON

JULY-AUGUST 1961

in this issue:

OPTICAL MASERS

VOLUME VI JULY-AUGUST 1961 NUMBER 1

ELECTRONIC PROGRESS

RAYTHEON

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COVER

This issue's cover reflects the broad scope of current electronics research and development. Raytheon interests extend from the intricacies of atomic structure to the global implications of arms control systems. The crystal structure depicted here is that of ruby—one of the active media that display maser action in the optical region of the spectrum.

Engineers and Registration

by DONALD E. GARR

The question of professional registration has been of concern to the design and development engineer for many years. The first engineering registration law was adopted in Wyoming in 1907 during an era of water conservation development. The law was enacted at the instigation of engineers of that state to protect the public from a flood of charlatans purporting to be qualified engineers. In the intervening years, all states have adopted laws governing the registration of engineers. The intent of Wyoming's law and all subsequent legislation has been to protect the public.

Mandatory registration for engineers engaged in public works is desirable and necessary. Safeguarding the public from unsafe products is quite another matter. The purchaser of a product is protected by the entire resources of the manufacturer who accepts responsibility for the design work performed by his design engineers. Mandatory registration for engineers engaged in product development offers no safeguard to the public and may impose unfair restraints on employee and employer.

Eighteen states, including those in which Raytheon has major operations, have clarified their engineering registration laws with a specific exemption for engineers employed by manufacturing companies. Various professional groups have aided in this development by drafting Model Engineering Laws with a view to attaining uniform high standards for model engineers throughout the United States.

Raytheon and similar companies producing products with a high engineering content have a major concern in engineering registration laws. First, we are vitally interested in advancing the professional stature of engineers and we recognize the role which registration plays in this process. Secondly, we are concerned that serious inequities may result if state laws are enacted without an adequate presentation of views from engineers and their employers.

We are fortunate that the states in which Raytheon has its principal operations have specified the exemptions described above. Future legislation which is in the best interest of the public and the engineers can be ensured only if each engineer acquaints himself with the facts and voices his opinion to his state legislator and his professional or technical society.

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Mr. Garr received a B.S.E.E. degree from Kansas State College in 1936 and has been awarded 19 patents. He is a Fellow of the AIEE; a Senior Member of the IRE; a Member of the ASME; and a Licensed Professional Engineer in New York State.

EP5

A milestone is an end and a beginning. With this issue, *Electronic Progress* begins its sixth year of publication. Its five-year growth closely parallels the Company's. Raytheon sales in 1956 were less than $200 million. In 1960 the figure exceeded $500 million. Employees now number approximately 40,000, nearly twice the 1956 total.

Electronic Progress was established as an internal communications medium for the technical staff, some 3500 copies of the first issue being printed. Over the years distribution has been extended to include government installations, customers, and individuals in colleges, schools, and industrial and academic laboratories. More than 12,000 copies of this issue were printed.

During this period, Raytheon's contributions to advances in the electronic industry have been reported in all branches of the technical press. Some of the more significant results have appeared in *Electronic Progress.*

The Amplitron—a device which increases by many orders of magnitude the potential for microwave power generation—was described in a 1957 issue. Pyrographite—a revolutionary high temperature material for space applications—was the subject of an article in 1960. Numerous papers on semiconductors, ferrites, dielectrics, and plastics have given exposure to Raytheon's broad program of materials research. The radar advancements discussed have been many, including progress in air traffic control, weather radar, MTI, frequency diversity and display techniques. The recent digital data processing issue announced the Cybertron, a self-organizing data processor which can learn. Raytheon's improved tubes and components have formed the basis of numerous articles. In this issue, the recently developed optical maser is discussed.

These advancements, and their subsequent reporting in *Electronic Progress*, are achievements of the Raytheon engineer or scientist. His skill, diligence in keeping abreast of his field, and acceptance of the challenge to extend the state of his art have been vital factors in the Company's success during the past five years. It is hoped that *Electronic Progress* has contributed to this effort by encouraging and abetting communication among the technical staff. The editors look forward to continuing this service as the Company attacks new problems created by a dynamic technology. As progress is achieved, we will report it here. The editorial staff welcomes your contributions.

THE PROBLEM OF ARMS CONTROL

by Clark C. Abt

"We intend to have a wider choice than humiliation or all-out nuclear action."

The President of the United States
July 25, 1961

CLAUSEWITZ once said that war is the continuation of policy by other means. In an age wherein war may cause unprecedented destruction, arms control offers the possibility of conflict by other, less destructive or more economical means. Arms controls are any measures, agreements, or techniques that will reduce the danger of all-out nuclear warfare, or limit the damage ensuing from less comprehensive conflicts *while at the same time maintaining national security in the face of protracted political conflict.* While total disarmament is one technique of arms limitation, for the foreseeable future it will not satisfy the requirement for national security in the face of protracted political conflict.

It has been argued that the very stabilization of deterrence implied by such stabilizing measures as improved force survivability and command and control tend to perpetuate the arms race. This view is sometimes held by those who also believe that the arms race is due to national insecurity as the result of the existence of military forces themselves. While undoubtedly there is a certain feedback among military competitors, as demonstrated by Richardson in his classic study of arms races, most students of strategy are agreed that the basic causes of arms races are political conflicts.

Arms controls must be understood within the context of the following assumptions: The United States

1. Maintains its political traditions and international autonomy;
2. Supports its Allies under formal treaty commitments, or neutrals by the request of the United Nations;
3. Resists Communist aggression and expansion wherever it may appear, continuing the grand strategy of containment.

Arms controls must reconcile the apparently conflicting requirements for resisting Communist aggression, by military force where needed, and at the same time, retarding the arms race. In particular, the diffusion of nuclear weapons to other countries must be retarded without endangering nuclear parity between the United States and the Soviet Union. The immediate objective has been that of maintaining stabilized deterrence by preventing pervasive technological superiority of either power block. The regulation and control of military forces and technology means neither the elimination of military technology nor its unrestricted growth. It does mean the careful guidance of military technology so that it is effective in maintaining those of our political objectives requiring military force, but also lends itself to the most discriminating application and stable employment.

The Contribution of Industry to the Solution of Arms Control Problems

Arms control problems must always deal with weapon technology. The larger military electronic and aircraft systems contractors have extensive experience in the conception, design, and development of entire weapons systems. This systems design and analysis capability is useful in two ways: First, forthcoming weapon systems under development could be improved in their discriminatory capacities and command and control functions, greatly aiding the solution of arms control problems. Second, is the application of system analysis and synthesis techniques learned in the development and comparative evaluation of weapon systems, to the larger policy problems of arms control. The system analyst's skills in probability and statistics, game theory, war gaming, and other preliminary design and evaluation techniques could be most useful.

Defense industries in general have the military systems synthesis and evaluation capability, and specific hardware research and development facilities to make substantial contributions to both theory and the technological implementation of arms control. The electronics industry has the unique capability to solve the large scale detection, communication, and data processing problems inherent in major arms control. At Raytheon, attention has focused both on strategic modeling of arms control interactions with weapons, and preliminary design studies of detection, processing, and communication systems for arms control applications.

Every citizen has a vested interest in arms control, because it may save his life, and possibly even reduce his taxes by reducing the cost of military security. The electronic engineer has an even stronger vested interest. Arms controls emphasize detection, communication, and data processing at the expense of warheads, power plants, and structures. Thus production of large scale arms control systems would shift the major share of defense contracting from the aircraft to electronic businesses.

Why Arms Controls are Urgently Required

The two fundamental reasons why national security can no longer depend on purely military strategy and weapons are the protracted political conflict with the nearly one billion people of the Communist block, and the technological explosion. The scientific revolution of the 17th and 18th centuries, followed by the technological and industrial revolutions of the 19th and 20th

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centuries, have made available military forces of unprecedented scope and destructiveness. The military technology explosion must be seen in the context of nearly 200 years of political revolutions among the major world powers. With the consolidation of the massive power blocks of Communism and the Western democracies, it was inevitable that technology would be fully exploited for military purposes. With the exploitation of technology for military purposes came massive Government support of scientific research and technological development, which, in turn, has accelerated the rate of technological innovation and scientific discovery.

It is this explosive rate of technological innovation that is responsible for the operational availability of hydrogen bombs and intercontinental ballistic missiles only 15 years after the end of World War II. The unprecedented destructive power in offensive weapons has not been matched by advances in the technology of defense. Even today, 15 years after World War II, no nation possesses a sufficiently effective defense against the manned bomber aircraft with nuclear weapons. Although both active and passive defenses against the new weapons are being and should be vigorously developed, they are unlikely to succeed in greatly reducing the damage that would be caused in nuclear war. Their chief purpose is the strategic one of maintaining a capacity to retaliate effectively after an enemy's surprise attack, the threat of this retaliatory attack hopefully acting as a deterrent to such aggression. *Thus the only high confidence method for avoiding the great damage that would ensue from an attack is to prevent the war.*

If the strategy of deterrence by threat of retaliation fails, even a limited nuclear exchange between the Communist block and the West may destroy industrial civilization and hundreds of millions of lives. Since the major protagonists may not survive such a conflict as national entities, dependence on the perfect functioning of such a strategy of risk alone is intolerable.

The unprecedented destructiveness and speed of delivery of modern weapons has made possible surprise attack over intercontinental distances. In previous wars, the geographical distribution of forces relative to the speed and range of delivery of weapons, and the rate of movement of defensive forces, always left time for mobilization of national, industrial and manpower resources for defense. Today, massive and survivable retaliatory forces must be maintained at constant readiness in order to make unattractive a disarming surprise attack by a potential aggressor. Until the retaliatory strategic deterrent forces of the major protagonists have been made relatively invulnerable to surprise attack, reciprocal fear of such attack will continue to threaten the possibility of "preemptive preemption"—which is a form of preventive war compressed in time.

A thermonuclear war may also be initiated through the miscalculated over-confidence of an aggressor, because of the relative unpredictability or inaccuracy of the *estimated* effectiveness of opposing deterrent forces. Limited local conflicts may "escalate" into general nuclear war, due to the inadequacy of conventional forces, or the temptation to gain a quick victory with the use of nuclear weapons if opposing forces are not similarly armed. General war can also occur through miscalculation if any of the major protagonists commit themselves to inextricable political positions for purposes of bluff, and the bluff is called.

The dangers of accidental initiation of a major war are much amplified by the great destructiveness of even individual weapons and their difficulty of recall, high penetration capability, and speed of response. The diffusion of nuclear weapons to less stable nations, with the possibility of local nuclear conflicts, further increases the danger of the major protagonists being drawn into a major thermonuclear exchange.

Through its threat of massive retaliation, the strategy of deterrence paradoxically may also increase the danger of accident, duè to the requirements for the survivability of retaliatory forces in the face of a disarming surprise attack. This survivability may be gained by very fast response, with reduced possibilities for analysis and evaluation of the situation, or on the other hand, by the dispersal mobility and concealment of retaliatory forces. Small, dispersed units are necessarily under the command of relatively low-ranking military officers, with the attendant danger of human error.

The stability of the strategic balance may be undermined by technological breakthroughs. Secret innovation of major weapon improvements by one side may tempt it to exploit a highly perishable advantage by massive surprise attack. This problem is not avoided by the mere addition of espionage and inspection so that military technological breakthroughs are quickly shared. Innovations may greatly reduce the cost of nuclear weapons and their delivery, with subsequent further diffusion of lethal strategic power.

Arms controls, unilateral or multilateral, tacit or negotiated, are the only means currently available for the stabilization of military security systems against these threats. Furthermore, the very concern with and the development of arms controls will force the protagonists of the protracted conflict to seek alternatives to the nuclear deterrent strategy. Already awareness of the inadequacy of the deterrent strategy of massive retaliation has led to increased emphasis on conventional military capability. However, even local wars limited to conventional weapons greatly increase the danger of escalation into general nuclear war. This is particularly the case if one side unwittingly expands the conflict by exploiting a tactical advantage to an extent that was mistakenly assumed to be within the scope of the operation.

Arms Control Plans

The interdependence of weapon inventory, capability, and innovation is reflected by arms control proposals that have attracted the most interest in recent years. These are the nuclear weapon test ban for the purpose of restraining the diffusion and improvement of nuclear weapons, Eisenhower's "Open Skies" plan for aerial inspection to reduce the probability of surprise attack, and more recently, the consideration of a ban on nuclear weapons in space. Other plans include mutual inspection of strategic forces to provide clear strategic warning, mutual agreement on and inspection of inventory levels for strategic deterrent stability, tacit and negotiated agreements not to employ nuclear weapons in local or limited wars, and agreements to desist from certain types of research and development.

Rather than stopping weapons tests, it may be possible to provide a schedule of costs and benefits for tests detected, and thereby provide a motivation for Soviet development of improved nuclear test ban monitoring methods. The idea would be to permit each side a "free" test for every one detected by them on the other side. The fact that the test has been detected would have to be verified by an international control council not subject to political pressure from either side.

Useful arms control plans cannot assume the solution of the very political problems they are intended to help solve. For example, grandiose plans for world government have sometimes assumed precisely the degree of international agreement on goals and methods that would make such a government unnecessary. Arms control plans must accept the present reality of world politics and protracted conflict before they can develop world government.

Some of the difficulties of developing a useful arms control plan are indicated by Table I.

TABLE I

CHECK POINTS FOR THE USEFULNESS OF AN ARMS CONTROL PLAN

1. Does it diminish the possibility of war through accident or planning?
2. Does it provide an effective means for rapidly terminating accidental or other wars?
3. Does it offer a realistic hope of limiting the number of nuclear nations and slowing the diffusion of nuclear weapons?
4. Does it have any promise of opening Soviet society to Western influence and inspection?
5. Does it gain the initiative for the United States in disarmament negotiations?
6. Does it help to advance the possibility of success in other areas of negotiation?
7. Does it reinforce the confidence of our allies in our political wisdom?
8. Does it contribute to relaxation of international tensions?
9. Does it convince other nations of our sincere desire to arrest the arms race?
10. Does it placate world opinion and convince people of our peaceful intentions?

Arms Control Systems as Strategic Equivalents to War

Arms controls may become the pursuit of military strategy by means other than war. It may be possible to devise non-violent means for improvements in the military balance of power. An arms control system with excellent communication between co-belligerents might fill this requirement. Explicit bargaining and exchanges of various strategic positions could improve minimum security of *all* antagonists. During times of political tension, a mutual inspection system could provide rapid verification of stabilizing movements made by potential belligerents in their mutual attempt to reassure each other that they are not preparing for a surprise attack. The possibility rests on the assumption that the parties to the control agreement have developed reasons for understanding that "win" strategies are not feasible, due to a balance of strategic power made possible by the arms control system itself.

Interdependence of Arms Control and Command and Control

The technical problems involved in the development of *secure* and *survivable* command and control communications will pose the major challenge to military technology for the next decade. It is also intrinsically a problem in arms control, for two reasons. First, the very political feasibility of certain military forces being equipped with nuclear weapons rests on the development of rapidly responding but tightly controlled command communications. Second, the conflicting objectives of extremely rapid reaction, flexibility of response to deal with unanticipated situations, and safety from accident or unauthorized initiation, require highly integrated efforts by both military system designers and strategists of arms controls.

The need to provide a nuclear backup to conventional capability to deter the enemy from employing nuclear weapons demands the most stringent control of tactical nuclear weapons on the highest policy level. It is essential to be able to respond with tactical nuclear weapons without the paralyzing delay of a piecemeal climb up the command ladder. Hence, the conflicting requirements of high policy level control of tactical nuclear weapons, and the need for very rapid and precise local response.

Another command and arms control problem is the proliferation of strategic bombardment weapons such as mobile ICBM's and IRBM's (Minuteman, Polaris, Skybolt). The proliferation, mobility and dispersion of strategic weapons is a response to survivability requirements and the obsolescence of hardening against improved warhead yield-accuracy combinations. The command and arms control problem is how to prevent

unauthorized or accidental employment of hundreds of extremely potent strategic weapons, any one of which could trigger a war. The problem is not merely one of control of the weapons, but also of providing a high reliability global communication link, possibly including one's enemies, for purposes of reassurance in the event that a weapon is discharged accidentally.

Space Weapons and Arms Control

Requirements for space weapons and arms control will sometimes conflict and sometimes re-enforce. Political interactions include international prestige, the effect of scientific leadership on appeals for technical aid from underdeveloped nations, and competitive exploration of space. (See Table II).

TABLE II

SPACE WEAPONS INTERACTIONS WITH ARMS CONTROL

1. How will space activities affect the international situation?
2. How can the United States manipulate space developments to improve its security?
3. How should the United States concert its space policy with other elements of its defense and domestic policies?
4. How does the reliability (or lack of it) of space-based weapons affect the probability of accidental war?
5. What are the special characteristics of space-based weapons that require unique arms controls? What controls?
6. How may space technology be exploited for surveillance and other systems for arms control?
7. Are space-based weapons as credible deterrents as surface-based ICBM's?
8. What unique threats are imposed by space weapons?
9. What unique strategic opportunities are provided by space weapons to the two major powers?
10. What elements of the space race threaten the stability of mutual deterrence, and how can they be controlled?

The fundamental problems of arms control of space weapons are the determination of military capabilities, limitation and discouragement of unstable space weapons, and detection of violations of arms control agreements. Evasion may be accomplished by injection of military payloads into orbit before the initiation of a control agreement, or violation of the control agreement after it is negotiated.

Because of the high expense of the space race, only a few countries will be able to afford participation in the race. Space weapons may soon help preserve the currently faltering "duopoly" of strategic deterrent power, maintaining this ultimate military threat for the exclusive use of the U. S. and U. S. S. R. for another generation.

Methods of Analysis

The analysis of technical arms control problems such as those listed in Table III, and the evaluation of various proposals to solve these problems have been hampered by a dichotomy of method. There is the approach made by the social and still relatively qualitative analysts (political scientists, sociologists, psychologists). There have also been the approaches by specialists in quantitative sciences such as physics, mathematics, and subordinate fields of engineering (electronics and astronautics).

These two groups do not share a common technical language. Perhaps the economists have the best training in both quantitative and qualitative thinking that helps to bridge the gap. They have been most prominent in the study of arms control problems that comprehend both quantitative and qualitative aspects (Schelling at Harvard, Morgenstern at Princeton, and Hitch at RAND).

There is little promise that the complex problems of arms control will be solved by "good practical thinking" about objectives, intuitive judging of alternatives, and subjective estimating of consequences. More specialized skills are required, but that does *not* mean specialized scope of operations. It *does* mean the application of specialized knowledge to a broad range of problems. Included in such problems may be requirements for expert scientific knowledge in rocket propulsion, seismology, electronics, nuclear weapon technology, and the combination of a large complex of factors that requires considerable mathematical skill and perhaps electronic computers to achieve a rapid solution. A methodology is needed to integrate military judgment, scientific knowledge, and political and strategic considerations.

TABLE III

TECHNICAL PROBLEMS OF ARMS CONTROL

1. To what extent do systems of surveillance depend on the general and detailed characteristics of weapon systems?
2. What is the complete chain of development of a lethal threat, through weapon study, design, development, production, deployment, operation and employment?
3. Which elements of the chain of design, development, tests, manufacture, storage, transportation, personnel training, delivery, and command communication, are most suitable for arms control surveillance?
4. What special materials are required for weapon manufacture, how are these materials processed, and what detectable proportion of the world supply does a significant weapon program require?
5. What is the minimum size of delivery vehicles, and what unique observables are there to these weapons and their launch sites?
6. How might war be initiated and proceed if both sides possess an *invulnerable* deterrent power?
7. How would war start and how would it proceed when the strategy is one of countering force, but that force is invulnerable? Does the action damp out, or is it prolonged?
8. Are current command control communications sufficient to prevent city strikes during the employment of counterforce strategies? (Consider the reliability and psychological factors among operating crews.)
9. Can arms controls reduce weapon inventories (and costs) sufficiently to maintain military security at reduced total cost? (The total cost must include arms control costs).

Although electronic systems and other technological devices can make a fundamental contribution to the problem of first stabilizing deterrence, and then inspecting international arms controls, it must not be assumed

that arms control is simply an engineering problem and that a physical system can solve any aspect of it. Lapses into "gadget worship" by enthusiasts have already bedevilled electronic data-processing where experience has shown that better machines are *not necessarily* a solution to *all* systems problems. This is why comprehensive studies of arms controls are best accomplished by interdisciplinary groups.

It has been claimed that arms control problems and specifically the question of the nuclear test ban, are not technical but political problems. This makes as much sense as saying that war is not a technical but a political problem. Certainly the basis of protracted conflict in either case is likely to be strongly political, as are the

TABLE IVA

SPECTRUM OF CONFLICT

Peaceful cooperation
Peaceful economic competition
Peaceful economic and political competition
Opposing, but unexercised military threats
Armed political insurrection (Cuba)
Armed political insurrection (externally supported "proxy" wars —Laos, Congo)
Brushfire wars (Indian-Chicom, Afghan-Pakistani skirmishes)
Local limited wars (Israel, Egypt, Korea)
Local nuclear wars
Limited theatre war (as in Central Europe)
Global limited war (World War II)
Unlimited theatre war
Unlimited global war

TABLE IVB

SPECTRUM OF ARMS CONTROL

No arms control required
Some tariff control
Tariff, currency and trade agreements
Unilateral stabilized deterrence by prevention of surprise attack
Agreement on restraint of development of difficult to control weapons
Exchanges of inspection teams for the limitation of weapons
Exchange of military staffs for inspection and hostages
Disarmament of unstable weapons
Substantial disarmament of strategic forces capable of *surprise* attack, *improved* conventional capability
"Across the board" disarmament down to the level of purely conventional forces
Total disarmament of all military forces
Disestablishment of military R&D
Disestablishment of military staffs and academies—total disarmament complete

solutions. The billions of dollars spent annually on military research and development, however, testify to the increasingly technological nature of the military problem. Since the basic aim of arms control is reduction of the danger of war and the limitation of damage if war cannot be prevented, it must be intimately concerned with the technology of weapons.

An example may serve to illustrate the interaction between political and technical factors. The continuation of the nuclear test ban depends on both the political question of communist China and France joining a global nuclear test ban, and the technical question of the feasibility of monitoring a test ban with a high confidence of detecting violations. India's reaction if the United States resumed testing is a political problem, and logistic support of an inspectorate is a technical problem (with political overtones).

It is possible to confuse technical with political problems because they can usually be expressed in terms of cost of solution. The question of whether this cost is worth the result then becomes a political problem. One might just as well argue, however, that the development of a new radar is primarily a political problem because it ultimately becomes a question of cost versus results obtained, and this is a decision that is made on the political level. Nevertheless, the design of radars is not usually left to politicians or administrators. One might argue just as mistakenly that engineers should make all political and administrative decisions, because ultimately the execution of policies is a matter of efficient allocation of resources and economical machinery for the accomplishment of objectives.

The Game Theory Approach

The mathematical expectation basic to game theory cannot by itself predict an outcome of a single military process, any more than a table of probabilities can predict the outcome of a single play of a game. Why then is it valuable? Game theory calculations are the only ones providing a rational basis for making *some* decisions. That such decisions cannot be predicted on a one-play basis does not invalidate the more important fact that, because these calculations must be made in order to determine the best strategy for a number of plays, it forces the strategists to make explicit and understandable their assumptions about how the game *should* be played. This elucidation of previously subjective and hidden reasoning may identify improved strategies. The investigation of game situations also makes it necessary to formulate precise definitions of terms which had previously been thought universally understood.

Arms control model simulation may fall into the categories of ideal and descriptive operations. The ideal model simulates a normative theory of strategy and control, while the empirical model simulates reality. Thus the discrepancy between normality and logic hopefully will be demonstrated with a constructive feedback into normality.

When an arms control model simulation is proposed as being applicable to the real world of military strategy, it becomes vulnerable to much more intensive evaluation than it would have as a theory. The heuristic theory is subject only to an analysis of the correctness of formal relations. On the other hand, as soon as the simulation purports to apply to the real world, critical evaluation will focus on the accuracy, realism and prediction capability of the model.

The "social physics" approach attempts to derive causes of behavior from aggregate data, suggesting that individual actions have negligible effect on major social outcomes. On the other hand, the game theory approach considers the individual moves in any strategic conflict, and attempts to provide a rational basis for the best choice of such moves. Game theory does not fail to take into account probabilities, but is concerned with individual plays rather than aggregate effects. "Social physics" is *statistical determinism* as exemplified by Richardson and Lanchester, versus *game theory* as exemplified by Schelling, Von Neumann, etc.

Game theory modeling is useful for the investigation of specific decision making, and statistical determinism is useful for the development of major national policies (but not specific strategic decisions). A useful integration of both methods is needed to provide a general model of the interactions between individual strategic decisions and major military economic trends. The development of the model itself is a technique for achieving this, since it provides a framework for the gaming of decision making.

In mathematical model simulations, the definition of *sane*, *rational*, or *logical* is usually in terms of what is simplest to understand. The obvious faults are that the *realism* of model decision making is extremely questionable, and that the model constrains even the logical possibilities to those inherent in the always necessarily simplified nature of the particular game that is being played. An aura of slightly smug, clever realism in the playing and evaluation of logical games may mislead the players and those briefed on the results into a strong feeling that they have penetrated the basic nature of strategic operations. Unfortunately, it is very unlikely that this is so.

TABLE V
SAMPLE GAMING OUTCOMES

OBJECTIVE	ALTERNATIVES	PLAUSIBLE COSTS	MODEL OPERATIONS	MERIT CRITERIA
Win	Peaceful Compromise	¼ Nation	Fraction of GNP Spent on Economic and Military Aid	Communist Satellites ↓ Neutrals → Allies
	War	½ Nation	Destruction	Years to "Recuperate"
Stability	Peaceful Compromise	¼ Nation	Fraction of GNP Spent on Economic and Military Aid	Neutrals Allies ↓ ↓ Allies Neutrals Neutrals ↓ Communists
	War	½ Nation	Destruction	Years to "Recuperate"
	Surrender	All of Nation	Occupation	Years to Successfully Rebel
Peace	Stability of Deterrence	¼—½ Nation	Fraction of GNP Spent Mostly on Military	Absence of War Limited Scope of Wars
	Surrender	All of Nation	Occupation	Years to Successfully Rebel

How are the great decisions made then? They must be some combination of logic, rationality, unconscious feelings (irrationality), irrelevancies (noise), habits, reflexes, etc. Which of these factors act as constraints, which act as motive forces, which are significant, which are trivial? Game theory provides a useful approach to the problem of "rational or possibly logical" decision making, in the sense of providing reproducible solutions to given problems, and providing logical solutions that are internally consistent within the conditions of the game. Unfortunately the decision-making process is probably a good deal more complex than a gaming matrix.

Arms control decisions must be evaluated by considering the validity of the purpose of the technique, how well it serves that purpose, the effects on force requirements and operations in general, the degree to which they complement or conflict with unilateral security requirements and operations, the effect on deterrence of peripheral aggression, what intelligence is provided to the participants, security problems that arise in discussion with allies and potential enemies, possibilities of enforcing agreements, and means of settling disputes about the interpretation of agreements. Not only the expectation or probability of various factors, but also their variance and frequency distribution, must be considered in the context of criteria for theoretical models: In model simulation, it must be assumed that long-range factors will depend chiefly on the structural constraints of the problem, rather than the transient psychology of decision makers. It can be argued that short-range decisions are a function of the immediate historic trends of decision making in a government, these decisions being made mostly on the basis of objective military, economic, and political forces operating on the leaders. The strategic model of arms controls is intended to be helpful to decision makers in the formulation of policy, by indicating the questions that should be asked, and the most critical alternatives. The model may thus provide a conceptual aid to the application of historic trends of decision making in a government, and relevant criteria to the choice of policies. The model serves as an educational tool emphasizing the basic operative principles between military strategy and arms control. This educational principle is the minimum value of the arms control model, and makes it worthwhile even if the quantitative analysis technique is incomplete.

Development of the model requires a clear statement of objectives, alternative solutions, and their relative costs. The systematic definition of these objectives, alternatives and costs is in itself worthwhile. In the analysis of alternatives, the imagination is focused on the problem in such a way that additional alternatives or systems are likely to be invented. Thus, by the manipulation of significant variables, it is possible to predict new relations that are not intuitively obvious, and hence test improved control systems and provide warning of new dangers. ■

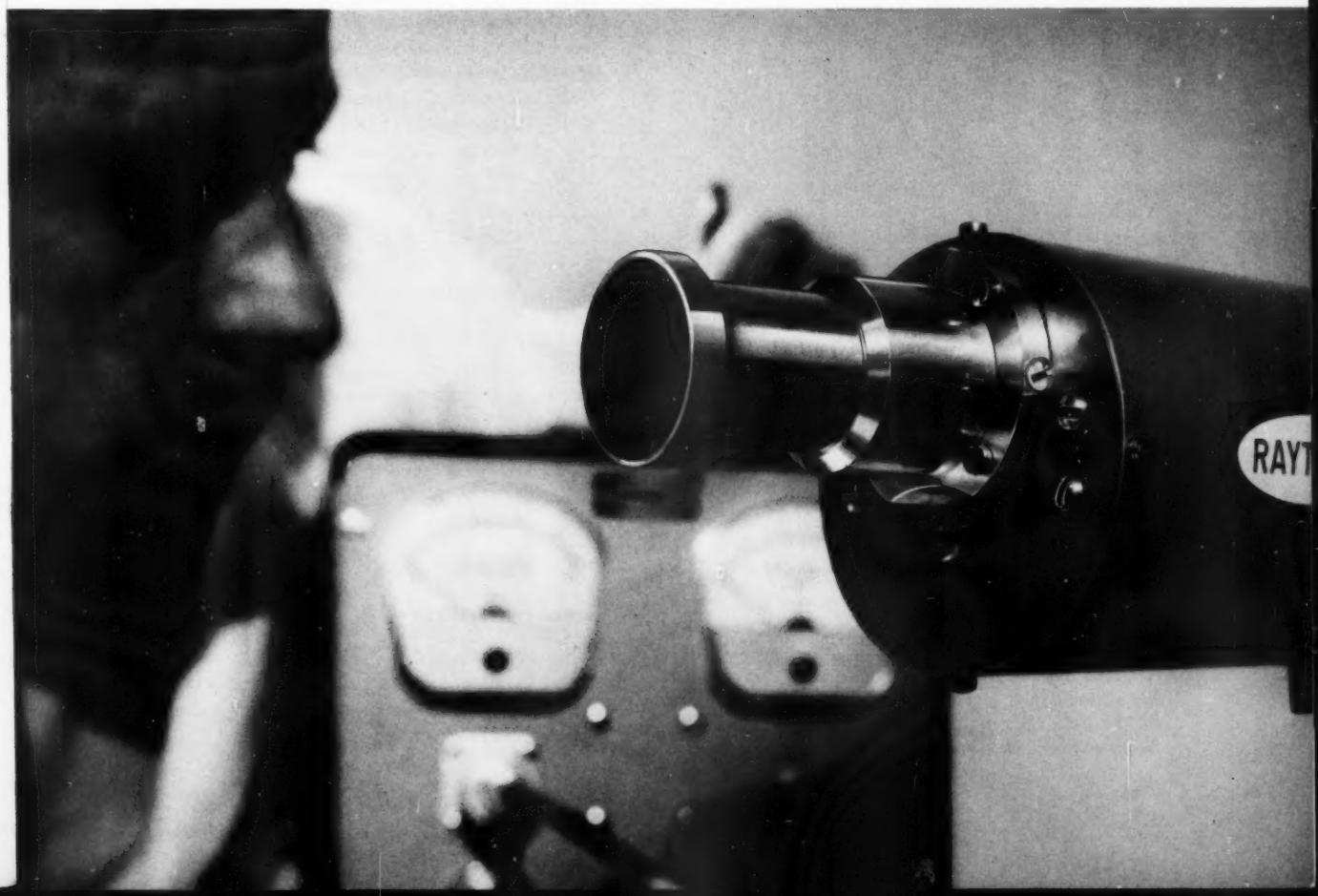
OPTICAL MASERS

by CLARENCE F. LUCK, JR.

AN OPTICAL MASER is a device which produces electromagnetic radiation in the optical region of the spectrum. This electromagnetic radiation has the subtle property of coherence. Coherent waves have surfaces of constant phase moving with the velocity of propagation away from the source. The wavelength spread of coherent radiation is very small, it is highly monochromatic. An ordinary incandescent bulb, like other conventional light sources, does not emit coherent radiation. A klystron oscillator does emit coherent waves (although not in the optical region). For some time scientists have sought a source of coherent radiation in the visible and near infrared regions of the electromagnetic spectrum. The optical maser is the first such source that has been discovered.

Electromagnetic Radiation—An Introduction

Fireworks to illumine the skies in celebration of special events have been used for centuries. The brilliant colors probably represent the earliest use of the light radiation characteristic of specific substances. Strontium salts were used for red, barium for green, for example. On the other hand, the control of the characteristic absorption of light in definite bands goes much farther



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back into antiquity. Dyestuffs and pigments were known to the ancients but the naturally occurring absorption bands peculiar to flowers, for example, must have been known to the most primitive of men. The colors of gem stones such as the ruby have been known and admired for thousands of years.

Modern physics has grown out of attempts to understand this light radiation and its interactions with matter. It was discovered early that white light consists of a mixture of all the colors. The prism which dispersed the white light into its components for Isaac Newton provided the key to spectroscopy. A slit was used to define the source beam. A system of lenses produced images of the slit on a screen, one image for each color. These images of the slit were lines of light. This is the origin of the term "spectral line."

The emission spectrum of hydrogen was organized by Balmer into a series of lines. Rydberg reduced the series to a mathematical formulation involving a constant. Bohr provided a theory which gave the exact value of Rydberg's empirical constant from fundamental properties of the electron and the nucleus of the hydrogen atom. Next, Schroedinger, Heisenberg and Born, among others, pioneered the development of a consistent theory which removed the arbitrariness of Bohr's quantization rules and solved many other problems as well. This body of theory is called Quantum Mechanics.

Thermocouples, bolometers, and photographic materials made possible the investigation of radiation effects beyond the visible limits. Longer and longer wavelengths occupy the region of the spectrum called the infrared. Lightweight diatomic molecules were discovered to have spectra due to rotation of the whole molecule. The study of these spectra in the extreme infrared made possible the calculation of the geometry of the molecules. Very early work in the microwave region was aimed at extending the molecular structure research to larger, more complex molecules. In 1934, Cleeton and Williams, using a series of tiny split anode magnetrons, verified a prediction based on quantum mechanical arguments by Hund that ammonia gas should exhibit a complex absorption spectrum in what is now called K-band. After the war, Gordy, Townes, Berringer and others[1] developed a system of extremely high resolution absorption spectroscopy using the reflex klystron.

This versatile tool made the determination of molecular structures an exact science. For example, methyl alcohol, CH_3OH, has been worked out exactly. The distances between the atoms and the relative orientations are known with extreme precision. For any kind of high resolution spectroscopy, the substance must in almost all cases be in the form of a vapor, otherwise the interaction between adjacent molecules broadens the lines too much to resolve.

A very few substances do exhibit sharp line spectra in the solid state. These spectra usually result from certain atoms embedded in a crystalline structure. Pink ruby is a material which exhibits a sharp line spectrum in the visible region. The sharp red lines are emitted when the ruby is exposed to light containing yellow-green-blue wavelengths. Ruby absorbs light energy in the yellow-green-blue portion of the spectrum and releases some of it at the longer red wavelength. This process is called fluorescence. The typical ruby red appearance is due to the absorption of all but the red incident light. The contribution of the red fluorescence is too weak to affect the appearance of the ruby. Of course, the sharp red emission lines can be readily detected with appropriate instruments.

Prior to the investigation of microwave spectroscopy, physicists had no coherent sources of radiation. In conventional absorption spectroscopy, a very broad source, frequently an incandescent body, is placed before what amounts to a tunable filter which admits only a relatively narrow range of wavelengths through the sample at a given instant of time. Thus the available energy is limited. The process is very inefficient.

A reflex klystron as used in microwave spectroscopy radiates only in an extremely narrow band of wavelengths. Instead of an adjustable dispersive element, the klystron itself may be tuned to produce different wavelengths to irradiate the sample. Unfortunately the klystron is limited to the microwave region of the electromagnetic spectrum although as mentioned previously, some very precise work has been done on molecular structure. By using crystal diode multipliers, Professor Gordy and his co-workers extended the effective range when they investigated the rotational spectrum of some simple diatomic molecules at frequencies up to 500 kilomegacycles. In a paper given at the Microwave Research Institute Symposium in the Spring of 1959, Professor Gordy described the Duke University millimeter wave spectroscopy program and listed a measurement on $O^{16}C^{12}S^{32}$ at 510, 457.3 megacycles per second[2].

From the far infrared wavelengths down to very short ultraviolet waves, no coherent radiation sources have existed until very recently. Dr. Arthur Schawlow of Bell

[1] Gordy, Smith and Trambarulo, *Microwave Spectroscopy* (John Wiley and Sons, New York, N. Y., 1953).

[2] Gordy et al., "Millimeter Waves in Physics," *Proceedings of the Symposium on Millimeter Waves* (Polytechnic Press, New York, N.Y., 1951).

Telephone Laboratories in 1958 predicted the form of a coherent radiator using a ruby crystal. Dr. T. H. Maiman, then of the Hughes Aircraft Company, finally succeeded in producing optical maser oscillations by this scheme in early 1960. Dr. Maiman used a ruby rod surrounded with a helical flash tube filled with xenon gas. Some wavelengths of the high intensity white light produced by the flash tube are absorbed by the ruby. A considerable portion of the total energy thus absorbed is re-emitted in a series of short pulses. The wavelength spread of the emitted red light is extremely small. In fact, the light within each pulse is coherent. History will record this important achievement as the first step in the discovery and utilization of a series of coherent light sources in the wavelength range shorter than the microwave limits. Some scientists even now consider the optical maser to contain greater scientific significance than the recent advances in rocketry.

It is only fitting that Bell Telephone Laboratories' workers should have succeeded next after Hughes in operating a ruby optical maser. Members of a team working in the Research Division of Raytheon Company were third to succeed in the production of a coherent light by a ruby optical maser. Other organizations followed suit shortly thereafter. Raytheon was the first to manufacture a completely engineered practical device. The optical maser offered for sale by the Special Microwave Devices Group is based on a high efficiency optical pumping concept evolved by the optical maser research team.

Other types of optical masers were announced by Drs. Sorokin and Stevenson of IBM and Dr. Ali Javan of Bell Telephone Laboratories. Dr. Javan's is quite different in that it employs a mixture of helium and neon gases. The IBM devices are somewhat similar to the ruby maser but employ different crystals and thus different wavelengths. Since the primary excitation in the gas maser is an easily obtained source of rf energy, the device can be operated continuously. It is the only type of optical maser so far reported which operates CW. Raytheon also has a helium-neon optical maser in operation.

The Ruby Optical Maser

The ruby optical maser is an energy converter. Electrical energy accumulated in a large capacitor is converted to a brief flash of electromagnetic energy at a wavelength of 6943 Å in the form of a coherent, self-collimated beam.

Ruby crystals consisting of a small percentage of chrome oxide in aluminum oxide exhibit a sharp line fluorescence (6943 Å and 6929 Å) at the red end of the visible spectrum as mentioned above. This is a result of modification of the chromium energy levels by the crystalline field. Figure 1 shows the pertinent energy levels schematically. Optical maser oscillations are intimately related to the fluorescence in ruby since the same energy levels are involved in both phenomena. Fluorescence

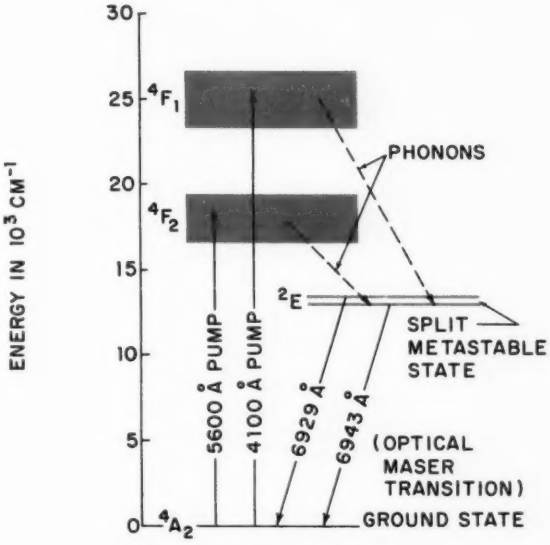

Figure 1. Energy levels in ruby

occurs as a result of absorption of wavelength bands of light centered about 5600 Å and 4100 Å. Energy thus absorbed is then partially given up to the crystal structure by radiationless transitions. The crystal lattice energy is gradually degraded to heat energy which is observed as a temperature rise in the cyrstal. This process leaves the ions of chromium in the two-fold metastable state characterized by ^2E in the figure. Transitions from the ^2E levels to the ground state produce the two close-spaced spectral lines at 6943 Å and 6929 Å responsible for the fluorescence. Transitions upward from the ground state result in excited atoms. Transitions constitute energy changes. Upward transitions absorb energy while downward transitions give up energy. If the transition is radiative, then light is either absorbed or emitted depending on whether the transition is upward or downward.

The absorptions in ruby at 5600 Å and 4100 Å may be called pumping transitions. The ^2E level is a bottleneck because the probability that an atom in the ^2E level will return to the ground state is relatively small. With sufficiently high intensity pumping, the number of atoms in the ^2E level tends to increase with time. Thus a population inversion can be realized. This means that the number in the upper state is greater than the number in the lower (ground) state.

A measure of transition probability is the reciprocal of the average lifetime an atom will spend in the given level with respect to the other level of the transition. The lifetime for the pumping transition is 10^{-5} seconds; for the radiationless transitions, 10^{-7} seconds; and for the fluorescence transitions, 5×10^{-3} seconds (the longer the lifetime, the less likely the transition).

When a beam of electromagnetic energy passes through a medium which gives up more energy to the

incident radiation than that which is absorbed, amplification results. Amplification is possible if the frequency of the incident radiation satisfies the well-known Bohr condition

$$hf = E_n - E_m \qquad (1)$$

and if the number of atoms in the upper state (which is E_n) is greater than those in the lower state E_m (h is Plank's constant, f is frequency).

An excess population in the ^2E state relative to the ground state is essential for optical maser action. A coherent beam of 6943 Å light falling on a ruby rod in which intense optical pumping has produced a population inversion in the corresponding level would emerge enhanced in intensity. If a feedback path is provided by placing reflecting surfaces at each end of a rod-shaped ruby, spontaneous emission noise at 6943 Å (^2E to ground state transition) will trigger an avalanche process as described below wherein the trapped radiation produces coherent stimulated emission. This oscillator is perhaps analogous to a reflex klystron which does not exist as such without its feedback mechanism.

Since the tangential electric field at each mirror must be zero, the radiation path between the mirrors must be an integral multiple of half wavelengths long. Thus the rod assumes the characteristics of a Fabry-Perot interferometer[3]. In order to couple the oscillation energy out of the resonator, one of the reflectors is made partially transmitting. This is similar to the microwave resonator formed by a short circuited waveguide with an iris an integral number of half wavelengths away from the short.

The ruby resonator is typically 6.0 cm long which means that the number of half wavelengths between the mirrors is of the order of 10^6. There are very many modes in which a resonator of this type can be excited. Modes for which the Poynting vector does not meet the end walls at right angles will travel sidewise on successive reflections through the rod—they will "walk-out" of the rod. This walk-out process reduces the effectiveness of any but the most nearly perpendicular-to-the-mirror modes. The mode selection process is the mechanism responsible for the sharp collimation of the output beam.

The optically pumped ruby within the resonator acts like an amplifier. The mirrors turn part of the amplified beam back into the active medium. The resulting feedback makes the maser a form of regenerative oscillator. Just as oscillation starts, the gain of a regenerative system approaches infinity and small effects, such as assymmetries in the ruby, are tremendously exaggerated (for example: other than zero orientation of the optic axis produces strong linear polarization).

The observed fluorescent linewidth is much broader than that expected from other properties. The width observed is strongly temperature dependent. Since the upper level responsible for the fluorescence is a result of internal crystalline field splitting, it is not surprising that temperature-dependent lattice vibrations can alter the separation from the ground state. Thus, the measured linewidth, which results from a larger number of atoms, is larger than the theoretical linewidth at room temperature. Inhomogeneities in the crystal resulting in each chromium ion not experiencing exactly the same field as every other, also produces some line broadening which is not temperature dependent. The widths of the resonator modes* are very sharp (high Q) and the modes are spaced about two kilomegacycles apart. Thus, coherent output is produced at a dozen or so frequencies separated by two kilomegacycles within the fluorescent linewidth.

When the optical maser has been pumped long enough to have a population excess in the upper state great enough to overcome losses, "noise" will cause oscillation to begin. This noise is a spontaneously occurring emission transition at 6943 Å (as in fluorescence). Radiation travelling back and forth in the Fabry-Perot resonator stimulates other excited atoms to emit radiation in step with itself. This cooperative stimulated emission on the part of the excess population of atoms in the upper state builds up very rapidly in an avalanche as the radiation intensity builds up. The rate of stimulated downward transition soon surpasses the rate of production of excited atoms by the pump process. The population excess is reduced to zero when the number in the upper state equals that in the lower. The radiation then dies out at a rate depending on the Q of the resonator. The pumping process can then take over again rebuilding the excess population in the upper state. As soon as the gain in the medium in the resonator equals the losses, oscillations build up again to produce another spike[4]. The series of output spikes continues until the pump light intensity drops too low to invert the population.

In the ruby optical maser, both the energy supply in the form of excited atoms and the intrinsic losses vary rapidly with time, giving rise to the spiking phenomenon as described above. By contrast, in ordinary oscillators the amplitude builds up until the energy consumed by the load plus the energy consumed by the losses equals the energy supplied to the system. Having reached this energy balance, the ordinary oscillator continues at a constant amplitude.

In order to achieve at least quasi CW operation, it is necessary to keep the rate of pump radiation-produced excess population equal to the maximum rate of signal

[3]F. A. Jenkins and H. E. White, *Fundamentals of Physical Optics* (McGraw-Hill Book Co., Inc., New York, N. Y., 1937), p.93.

*A resonator mode is defined here as a field configuration in the resonator corresponding to n half-wavelengths between the mirrors. The value of n characterizes the mode.

[4]H. Statz, C. Luck, C. Shafer and M. Ciftan, *Observation on Oscillation Spikes in Multimode Lasers*, Second International Conference on Quantum Electronics, Berkeley, Calif. (March 23-25, 1961).

frequency transitions to the ground state at all times. The obvious solution is to provide an enormously intense pumping light. It is probable that other solutions will also be found.

At the present writing, a continuously pumped ruby optical maser has not been reported. Only xenon filled flash tubes have been found to have sufficient intensity to pump the crystal to an excess population in the ^2E level. Several other solid state optical maser schemes show promise as continuously pumped optical masers.

In the Research Division at Raytheon, a high-efficiency optical pumping scheme has been devised.[5] An elliptical cross-section cylindrical reflector with plane ends perpendicular to the cylinder axis will produce an image at one focus of a line source located at the other focus. Practically all of the light emitted by the source will be collected at the position of the image. A straight line flash tube is used as the source while a ruby rod is placed at the other focus. One partially reflecting end of the ruby rod is exposed outside the reflecting cavity. The maser beam is emitted from this surface. Figure 2 shows an opened view of the laboratory prototype of this scheme. Figure 3 is a view of the production model optical maser head manufactured by the Special Microwave Devices Operation of Raytheon. On June 20, 1961 the engineering group at Special Microwave Devices succeeded in operating the maser at a threshold of only 70 watt-seconds input energy. This is a good measure of success in obtaining efficient optical pumping since the typical helical type optical maser requires approximately 2000 watt-seconds input energy at threshold.

The power supply for a flash tube operated optical maser consists of a large capacitor bank for storing the energy. The bank is charged from a small controllable dc supply. The flash tube is triggered with a high voltage transient pulse. When the tube is fired, the current flows through an inductance to increase the time duration of the flash and to limit the peak current.

Experiments at Low Temperature

As suggested in the previous discussion, the threshold input energy is strongly temperature dependent. Rough experiments performed by blowing cold dry nitrogen (cooled by passage through a copper coil immersed in liquid nitrogen) over the ruby rod have indicated that the output for a given input rises rapidly as the temperature goes down. Conversely, if the ruby is not allowed to cool down sufficiently between shots, the output falls and the threshold rises.

Other materials such as uranium ions in a calcium fluoride crystal can barely be made to work at room temperature. In these materials, the optical maser transition does not go to the ground state but rather to some level above the ground state. The equilibrium

[5]M. Ciftan, C. Luck, C. Shafer, and H. Statz, "A Ruby Laser with an Elliptic Configuration," Proc. I.R.E. **49** (May, 1961).

Figure 2. Laboratory prototype of elliptical optical maser

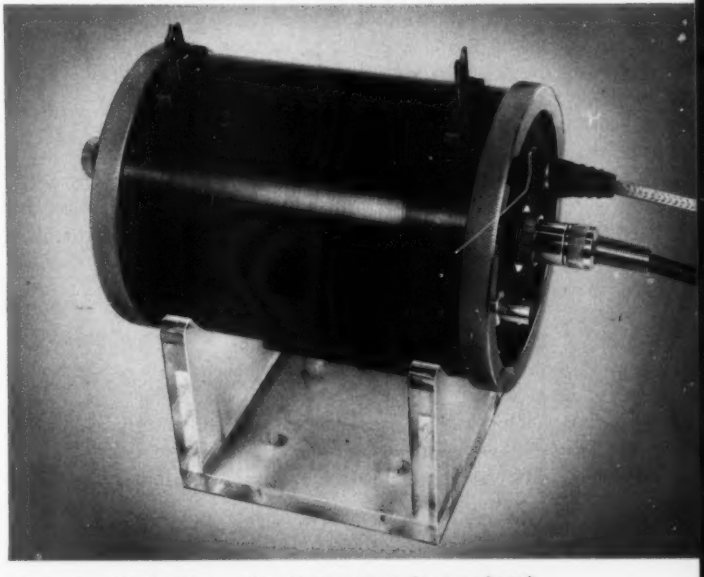

Figure 3. Production model of ruby optical maser head

populations of levels above the ground state are reduced by cooling. Therefore, the desired inverted population can be achieved at lower optical pumping inputs when the crystal is cooled. If enough cooling can be achieved efficiently, it is conceivable that the threshold will be reduced enough to be within the capability of lamps other than xenon flash tubes. A high intensity lamp such as a continuously operating mercury vapor arc may then be used to accomplish CW operation. At the same time, dissipation of the lattice heat energy is facilitated because many of these crystals become good thermal conductors when cooled well below liquid nitrogen temperatures.

The foregoing considerations have led to the design and construction of a cryostat optical maser in the Research Division. This device, which is nearly completed, is shown in Figure 4.

Elliptical reflectors are used to obtain efficient optical pumping. The pumping lamp is located outside the vacuum so that cooling and adjustments to the lamp are simplified. The crystal is connected internally to a liquid helium reservoir with which it should be possible to cool down to approximately 20° Kelvin.

The Gas Phase Optical Maser

As mentioned previously, sharp line spectra are more typical of gases than solids. It might seem then that a gas filled Fabry-Perot resonator would be a more likely candidate than the ruby for a successful optical maser. The difficulty lies in the possible methods of obtaining the necessary population inversion. In ruby, the two broad optical pumping bands soak up an enormous amount of energy compared to that which would be absorbed by sharp lines. With sharp lines to pump, the pump light must either match exactly in wavelength or if white light is used, the intensity would have to be tremendous since only an extremely small slice of the total output satisfies the Bohr condition (Equation 1). This is extremely inefficient.

Dr. Ali Javan of the Bell Telephone Laboratories[6] worked out an elegant scheme for obtaining population inversion (and thus "gain" it will be recalled) by a resonant energy transfer brought about by an electrical discharge which takes place in a mixture of two gases. The energy is actually transferred at the instant of collision between the two kinds of atoms involved. Fortunately, the gases which have been found to work, helium and neon, are inert and no chemical reactions or molecular interactions can occur to complicate the process.

Consider first only the helium gas. Helium has two electrons circulating about its nucleus. These electrons can have their electron spins aligned either parallel to each other or anti-parallel. If they are parallel, the net spin is unity; if they are anti-parallel, the net spin is zero. The zero spin has less energy than the other case and so the ground state, or lowest energy state has zero spin. In a container of helium gas in the absence of any excitation process, there is no reason for atoms with parallel spins to have one of their electrons flip over and become a zero electron spin atom. This leads to two series or systems of spectral lines for helium. The lowest energy level for the parallel spin configuration is considerably above the ground state for helium and yet the atoms which end up in this so-called metastable level cannot make transitions to the ground state. A certain amount of energy is trapped in these parallel spin atoms.

Figure 4. Cryostat optical maser

Fortunately for optical maser builders, neon has an energy level very close to the helium metastable energy level above the ground state. Collisions between metastable helium atoms and ground state neon atoms have a high probability of energy transfer from the helium to the neon. The parallel spins in the helium become anti-parallel and the energy is given up to the neon while the helium is returned to its (anti-parallel spin) ground state configuration. Thus the neon gas will have an increase in the population in the level excited by the collisions.

Of course once the neon provides the mechanism for all the parallel spin heliums to become anti-parallel and return to their ground state, that would be the end of it. However, an electrical discharge (obtained by rf excitation of 50 watts at 27 megacycles) in the gas mixture, which is the mechanism by which energy is supplied to the maser, actually ionizes the helium atoms. When the electrons removed by ionization fall back into their orbits, they may fall back with spins either way. A fair percentage recombine as parallel spin atoms and so the supply of metastable helium atoms is replenished. The process can then be made to continue.

The excited neon atoms return to the neon ground state by a series of transitions between the several neon levels leading to the ground state. There are some

[6] A. Javan, W. R. Bennett, Jr., and D. R. Herriott, "Population Inversion and Continuous Optical Maser Oscillation in a Gas Discharge Containing a He-Ne Mixture," Phys. Rev. Letters **6** 106-110(1961).

Figure 5. Helium-Neon gaseous optical maser

sixteen transitions which should lead to optical maser action in the wavelength region around 1.2 microns (12,000 Å). Of these, only five or so can be observed with a given maser since the reflecting coatings at the ends of the Fabry-Perot resonator can be made to have sufficient reflectivity only over a very limited wavelength range. Outside of this range, there is not enough feedback to support oscillation. The relative transition probabilities for all of the possible maser lines has been calculated.[7]

The ruby optical maser seems to be capable of enormous powers over very short times, while the gas phase optical maser, due to the very low gas density compared to the solid case, has produced only 15 milliwatts but this output can be sustained indefinitely, according to Dr. Javan. As a result of the extremely high resonator Q and the long time operation, the linewidth of the radiation from the gas maser is very narrow, probably only a few hundred cycles per second. There are actually several such lines separated by about 148 megacycles corresponding to successive resonator modes. Many interesting experiments can be devised for this really coherent source of radiation.

The promise of the CW gas phase optical maser is very good. Accordingly, the Raytheon Research Division has begun a program for research on gas masers. The first experimental helium-neon device, shown in Figure 5, operated successfully for the first time on June 26, 1961. Its framework is built of Invar. The critical adjustments of the parallelism of the interferometer mirrors, which are actually high precision commercial grade quartz optical flats, are made with fine pitch differential screws and adjustable compression springs. The gas envelope parts are sealed together in the manner of a vacuum tube. Since the maser must be demountable at this phase of the research, only copper gaskets have been used. The vacuum system as well as the maser itself can be baked out just like a tube.

Pending the outcome of experiments with the prototype, future plans include a simplified, easily aligned, sealed-off version of the optical maser. Research involving the interactions of the radiation from more than one mode in the gas phase maser will provide interesting information on photo-electric mixing. A program to investigate modulation and detection techniques in conjunction with optical masers has been launched in the Research Division.

Conclusion

The ruby optical maser is that rare device which is exquisitely simple and yet employs ideas based on the most advanced quantum mechanical theories. From the scientist's point of view, it is beautiful. The helium-neon gas phase optical maser is certainly no less beautiful because of its greater complexity.

No long list of accomplished applications exists. The lists of fancied applications are sometimes quite bizarre. The properties of optical masers are just too new to fit into established patterns. Physicists have for decades been conditioned to think that there are no coherent sources of light. Under these terms, very little thought could have been given to the uses of coherent sources.

On the other hand, microwave people have been dealing with coherent radiation all the time. Thus it is easy to fall into a trap—the microwave analog approach. The optical maser is not merely a microwave tube with a hitherto unrealized wavelength. Although the whole spectrum of electromagnetic energy is essentially the same from the Maxwellian point of view, different regions behave very differently in their interactions with matter. Granting that (for economic reasons) the microwave analog approach is perhaps a good first approximation, it is essential to keep in mind that greater potential may lie in at present undreamed of directions.

[7]G. Koster and H. Statz, "Probabilities for the Neon Laser Transitions," J. Appl. Phys. (to be published).

PRINCIPLES OF

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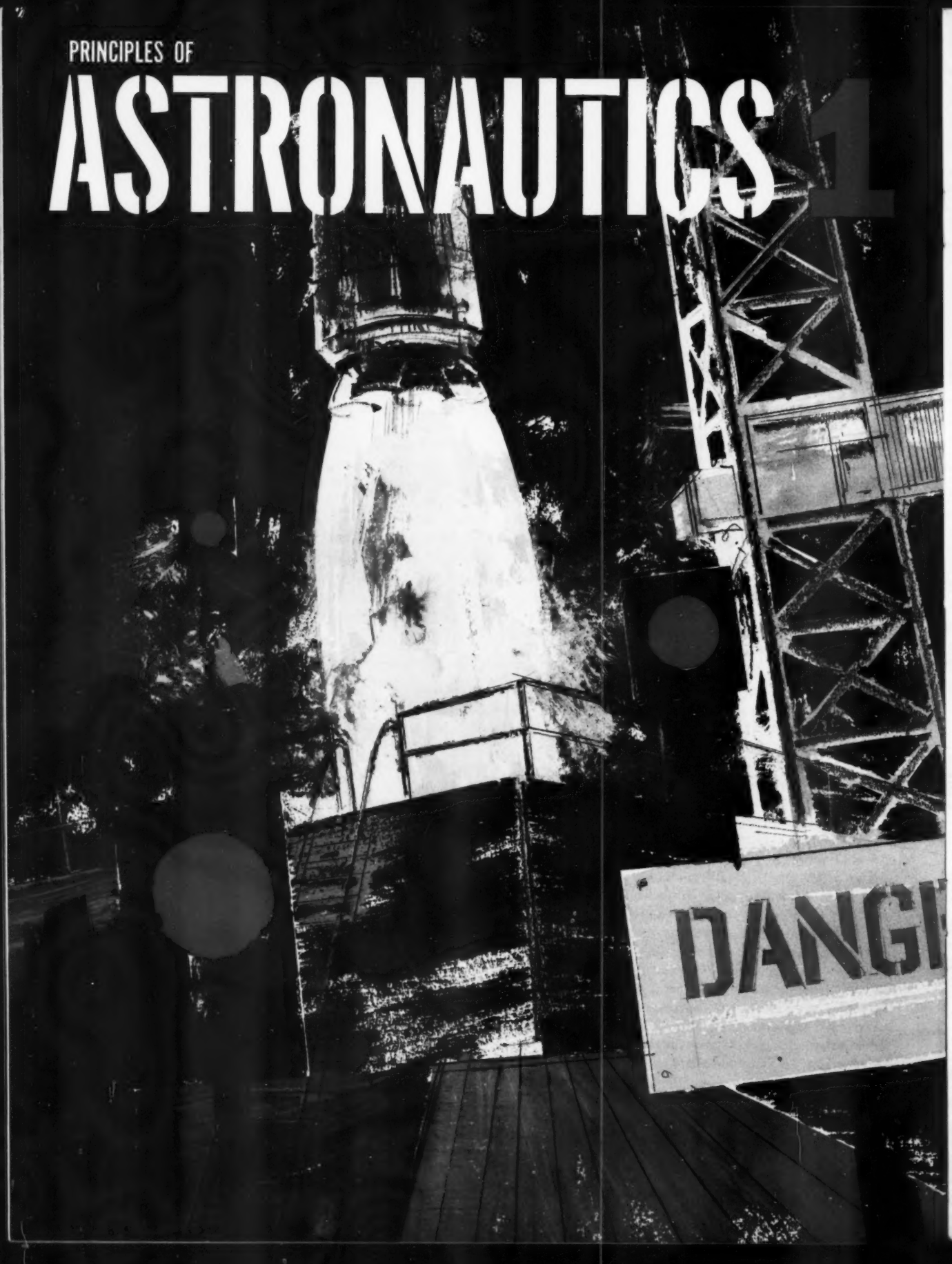

by GERALD A. OUELLETTE

LAUNCH MECHANICS OF SPACE VEHICLES

THE LAUNCHING PHASE of a space vehicle serves the sole purpose of imparting a velocity to the vehicle so that its subsequent motion under the influence of gravitational forces satisfies specified mission requirements. Vehicular motion during the powered phase thus describes a trajectory that attains the desired end conditions as efficiently as possible, subject to physical limitations of the vehicle and its payload. For this discussion, the launch mechanics of a satellite vehicle are investigated, since it is simpler to use a specific example rather than to generalize.

The establishment of an artificial satellite consists of accelerating a vehicle to a velocity such that the gravitational attraction of the Earth is incapable of curving its path sufficiently to intersect the Earth's surface. This can be likened to firing shells from a rifle horizontally with increasingly higher muzzle velocities. For small velocities the gravity component curves the trajectory and the shell eventually strikes the ground. As the muzzle velocity is increased, the range increases until finally the curvature of the trajectory equals that of the Earth and the range becomes infinite as illustrated in Figure 1 by curves I, II, and III. For still larger values of velocity the motion becomes elliptical (curve IV) then parabolic (curve V) and finally hyperbolic. For infinitely large values of muzzle velocity the resulting motion is a straight line.

From simple mechanics and Newton's law of gravitation, the velocity necessary to establish the circular motion as shown by curve III is

$$\frac{v^2}{r} = g_{local} = \frac{\mu^2}{r^2} \qquad (1)$$

$$\text{or } v = \frac{\mu}{\sqrt{r}} \qquad (2)$$

where v^2/r is centripetal acceleration, μ^2/r^2 is gravitational acceleration, r is orbital radius, and μ^2 is gravity constant. Aerodynamic drag precludes this type of motion close to the Earth's surface and satellite motion is possible only outside of the appreciable atmosphere. For this reason, some means must be provided for lifting the vehicle above the atmosphere and then accelerating it to satellite velocity.

The only known method for lifting a vehicle against gravity without a surface to react against is to exert a thrust force in excess of the local gravity force on the vehicle through the use of a rocket engine. The differential force acting on the vehicle will accelerate it to some desired velocity so that, when the thrust force is reduced to zero, the vehicle will coast up to the desired altitude. The flight path of the vehicle after thrust termination is a portion of a conic section, as is all free-fall motion under the influence of a central gravitational force. The desired cut-off conditions of the rocket booster are therefore the velocity and radius vectors that define a conic section which intersects the final orbit as shown in Figure 2.

Optimized Trajectories

During the thrust phase, the rocket engines are performing work on the unburned propellant remaining with the vehicle as it moves up in the Earth's potential field. This wasted energy can be gainfully transferred to the payload if the vehicle does not climb appreciably during the thrust phase, i.e., if nearly impulsive thrusting is utilized. From a propulsive standpoint, this represents the most efficient operation; however, the high accelerations may produce deleterious effects on the vehicle, and the resultant high velocity at a low altitude will produce excessive aerodynamic heating and drag. It is apparent, therefore, that the optimum thrust program requires a high initial boost phase followed by a lower level sustainer phase. For a single

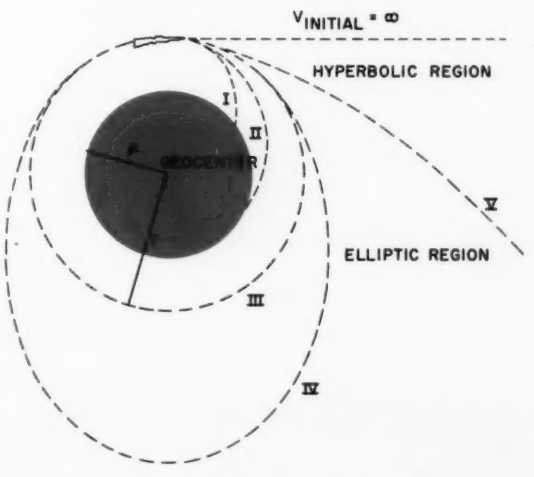

Figure 1. Effects of increasing velocity on the free-fall motion of a projectile under the influence of a central gravitational force

stage vehicle, this optimum utilizes the maximum permissible thrust until the quantity $v\partial D/\partial v - (1 + v/c)D$ equals the gravitational force on the vehicle, W. Here D is the drag force, v is vehicle velocity, and c is the exhaust velocity of the propellant. The thrust is then adjusted to maintain this equality until the desired cut-off conditions are attained. Conventional satellite launching vehicles do not adhere to this optimum technique exactly, since the required thrust levels and control capability are not practical in large vehicles. The vehicle acceleration and thrust versus time profiles for an optimum thrust program are illustrated in Figure 3a and typical space booster acceleration and thrust profiles are shown in Figure 3b. The required thrust variations for an optimum program illustrated in Figure 3a show a time dependence whereas constant thrust is illustrated in Figure 3b. The slight increase in the first stage thrust in Figure 3b is due to decreasing effects of atmospheric density on thrust as the vehicle's altitude increases. The thrust and acceleration curves in Figure 3 drop to zero when the vehicle attains the specified burnout conditions.

In a previous paper ("Rocket Propulsion," ELECTRONIC PROGRESS, January-February 1959) it was shown that the ideal velocity capability of a rocket vehicle is given by the equation

$$v_c = \sum_{c=1}^{n} c_i \ln R_i \qquad (3)$$

where

c_i = exhaust velocity of the i^{th} stage

and

R_i = mass ratio of the i^{th} stage.

$$R_i = \frac{m_{oi}}{m_{oi} - \dot{m}_i \tau_i} \qquad (4)$$

where

m_{oi} = initial mass of i^{th} stage,

$\dot{m}_i$ = mass flow rate of i^{th} stage (assumed constant)

τ_i = burning time of i^{th} stage.

(Mass ratio is the ratio of the initial mass or weight of a rocket to the final mass or weight.) Since the final mass

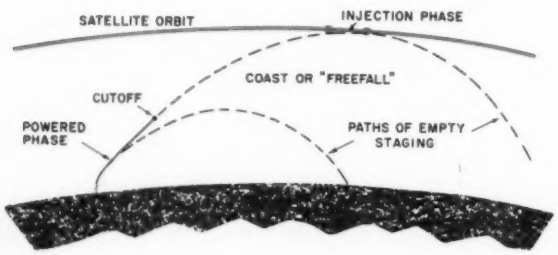

Figure 2. Typical ascent trajectory of a three-stage satellite launching vehicle

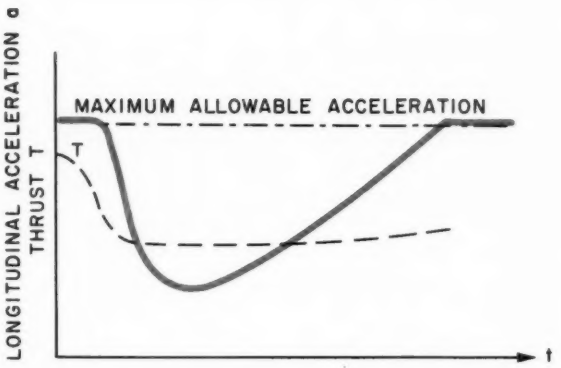

Figure 3a. Optimum acceleration and thrust profile

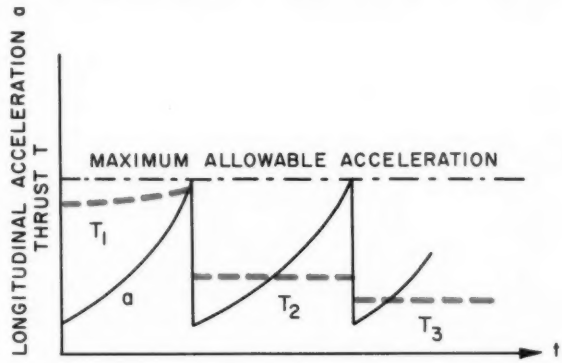

Figure 3b. Practical acceleration and thrust profiles for multi-stage space boosters

of a stage ($m_{oi} - \dot{m}_i \tau_i$), appearing as the denominator of Equation 4, represents inert structure of the i^{th} stage and its payload, the capability of a vehicle is improved by minimizing the structural weight of the vehicle. In doing this, the strength of large vehicles is decreased to a point where they cannot support their own weight while resting on the earth's surface. Large liquid propellant rockets overcome this difficulty and improve the longitudinal compressive structural strength by pressurizing the propellant tanks to several pounds per square inch above atmospheric pressure. This preferred structural direction precludes launching at any declination angle other than near vertical.

GERALD A. OUELLETTE *is Head, Space Section, Aerophysics Department, Missile and Space Division. He joined Raytheon in 1955 where he has performed astronautical studies, system and analysis studies on Sparrow III, and aero-dynamic studies on the Hawk. During 1959-1960 he was engaged in analytical studies for satellite rendezvous at the M. I. T. Instrumentation Laboratory. He returned to Raytheon in 1960 and, at present, is analyzing space operations to establish mission criteria and vehicle requirements. This includes problems associated with project Prospector, Apollo, Bambi, and the High Orbital Satellite System. Mr. Ouellette received an A.B. in physics from Harvard; has done graduate study at Harvard and M. I. T.; and lectures on astronautics in the Physics and Astronomy Department at Boston University.*

Unfortunately, near vertical powered motion under the influence of gravity wastes energy because the total gravity vector opposes the thrust vector. For this reason, the flight path angle of a launching vehicle is reduced as quickly as possible after launch, consistent with maximum allowable aerodynamic loads. Although the drag losses due to the extended path length in the appreciable atmosphere are increased, the reduction in gravity losses overshadows them. The vertical flight portion terminates somewhere between ten and forty seconds and pitch-over terminates at approximately 130 seconds for currently operational space boosters. The vehicle then maintains a constant flight path angle in inertial space until burnout to minimize propellant consumption. (See Figure 4.) This type of trajectory represents a close approximation to an optimum flight path wherein the vehicle maintains a constant attitude during the entire thrust phase.

The most economical thrust direction program for a space vehicle booster is to thrust at a constant attitude in inertial space for the entire burning phase. The qualitative proof of this statement is apparent from Figure 5a where the vector $\vec{v}_o$ represents the vehicle cut-off velocity and the vector $\vec{v}_c$ represents the velocity the vehicle would have if gravity were not present. The integrated gravitational acceleration $\int g dt$ added to $\vec{v}_c$ produces $\vec{v}_o$. If the thrust angle deviated from $\vec{v}_c$, the resultant lateral component of velocity would cause $\vec{v}_c$ to rotate and, unless compensated for by an equal and opposite component, $\vec{v}_c + \int g dt$ would not produce the desired $\vec{v}_o$. Since additional propellant would be required to compensate for deviations, it is apparent that a constant thrust attitude program is the most economical. The hodograph of a typical ascent thrust phase is illustrated in Figure 5b where the effects of vertical launching and aerodynamic losses are included.

Equations of Motion

The equations of motion of the ascending vehicle can be written in two dimensions since motion under a central force must be planar. Atmospheric effects, earth peripheral velocity, and oblateness effects will perturb the vehicle in three dimensions and must be included in

This paper is the first of a five-article series entitled "Principles of Astronautics" by G. Ouellette which is being published in ELECTRONIC PROGRESS. The series will cover the following topics:

1. Launch Mechanics of Space Vehicles
2. Planetary Artificial Satellites
3. Interplanetary Transfer
4. Entry into Planetary Atmospheres
5. Man in Space

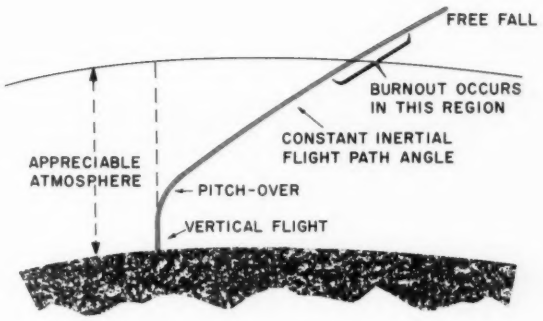

Figure 4.
Phases of powered flight of a typical booster vehicle

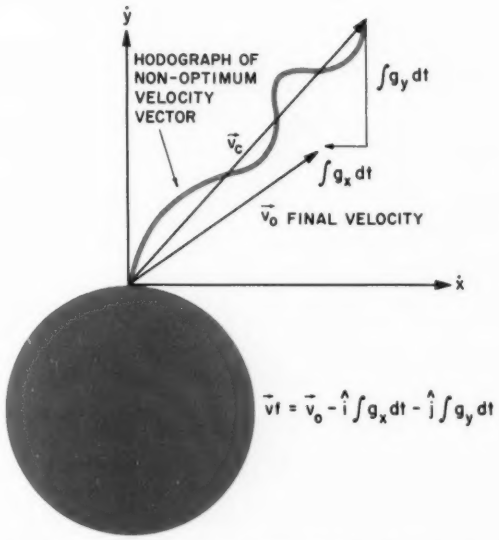

Figure 5a. Hodograph of velocity vectors illustrating optimum thrust direction and gravity losses

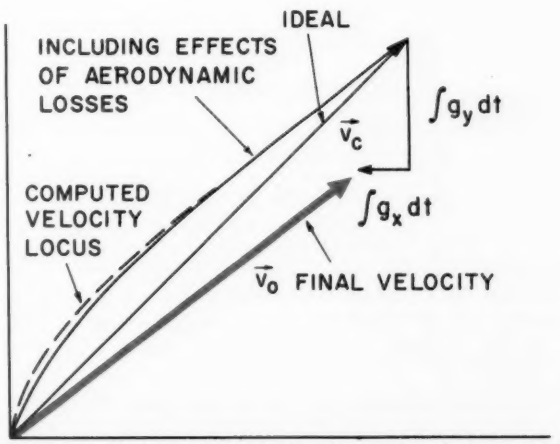

Figure 5b. Hodograph of ideal and realistic velocity vectors

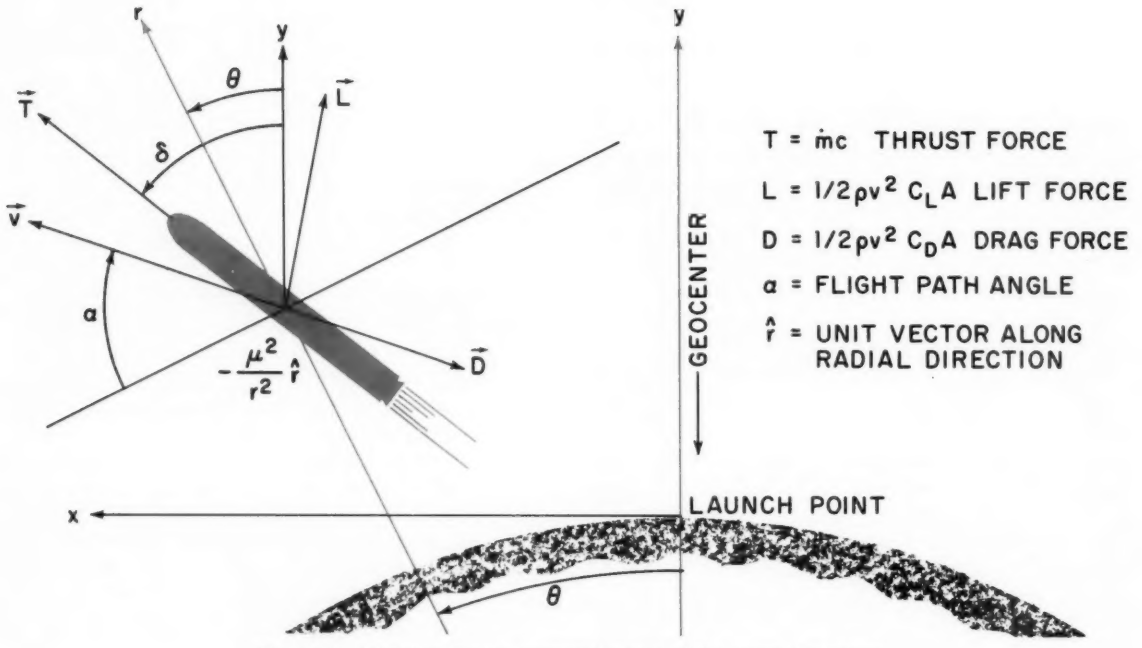

Figure 6. Notation for the powered phase of the ascent trajectory

an exact analysis but are neglected here. Using the notation in Figure 6, the equations of motion are:

Radial acceleration,

$$\ddot{r} - r\dot{\theta}^2 = \frac{T}{m}\cos(\delta - \theta) - \frac{1}{2}\rho v^2 A (C_D \sin\beta + C_L \cos\beta) - \frac{\mu^2}{r^2}; \quad (5)$$

Circumferential acceleration,

$$r\ddot{\theta} + 2\dot{r}\dot{\theta} = \frac{T}{m}\sin(\delta - \theta) - \frac{1}{2}\rho v^2 A (C_D \cos\beta - C_L \sin\beta); \quad (6)$$

where

T = thrust = $\dot{m}c$

m = instantaneous mass = $m_o - \dot{m}\tau$

ρ = atmospheric density

A = reference area

C_D = aerodynamic drag coefficient

C_L = aerodynamic lift coefficient

$\frac{1}{2}\rho v^2$ = dynamic pressure

Outside of the appreciable atmosphere where the dynamic pressure is very small, these equations become:

Radial acceleration,

$$\ddot{r} - r\dot{\theta}^2 = \frac{T}{m}\cos(\delta - \theta) - \frac{\mu^2}{r^2}; \quad (7)$$

Circumferential acceleration,

$$r\ddot{\theta} + 2\dot{r}\dot{\theta} = \frac{T}{m}\sin(\delta - \theta). \quad (8)$$

Equations 5 through 8 are not amenable to analytical techniques and must be solved by numerical quadrature. The difficulties associated with establishing a reference trajectory are apparent when the end (burnout) conditions are specified to satisfy a particular mission, since an iterative procedure must be used to determine the trajectory that best satisfies these conditions. More generally, a reference trajectory for a specific space booster is specified with variable end conditions based on time of flight and payload weights, and these conditions are matched to a specific mission.

The Russian Venus Probe launched on February 12, 1961, utilized this latter technique by flying the best trajectory with arbitrary end conditions to a low satellite orbit. The Venus trajectory initial conditions were then matched to a reference orbital departure trajectory, thus relaxing the time-of-launch and ascent trajectory constraints.

Launch Trajectory Profiles

In general, four types of ascent trajectories can be used for satellite launching. They are illustrated qualitatively in Figure 7. The type used for a particular mission is determined by the vehicle characteristics and the minimum radius of the desired orbit.

For establishing very low orbits the powered-all-the-way trajectory is utilized if the burnout altitude of the booster vehicle generally exceeds the orbital altitude. This technique is extremely wasteful of propellant for establishing high orbits and is not used in current space

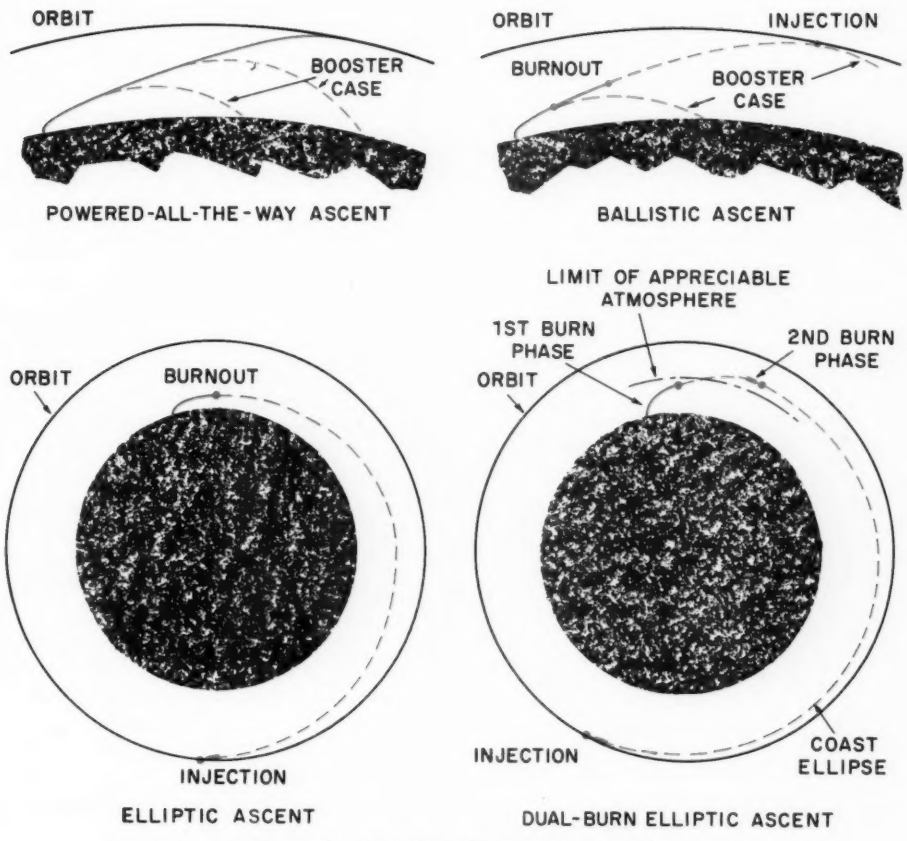

Figure 7. Typical satellite launch trajectories

projects. The ballistic ascent is perhaps the most common trajectory used to establish satellites in low to moderate altitude orbits. It consists of an initial powered phase during which the vehicle is accelerated to some specified velocity at which time the thrust is terminated and the vehicle coasts along a trajectory that carries it to the desired altitude, where the satellite is injected into orbit by an additional thrust phase. This type of trajectory poses the least problems since it makes efficient use of the propellant, and the vehicle can be tracked until orbital injection with a minimal of tracking sites.

For high orbital altitudes, the ballistic ascent range is extended until the geocentric angle between initial burnout and orbital injection reaches 180 degrees. If injection does not take place, the vehicle moves in an elliptic orbit about the Earth passing through the original burnout point. Since the vehicle moves in an elliptic trajectory which does not intersect the Earth's surface, the term ballistic gives way to elliptic. This is the most efficient trajectory in terms of propellant for establishing a satellite orbit; however, the tracking problem is more severe than in the ballistic case and aerodynamic losses are increased due to the long path in the atmosphere. The aerodynamic losses for the elliptic ascent can be reduced by using the dual burn technique whereby the initial powered phase puts the vehicle on a shallow ballistic trajectory whose apogee point is just above the appreciable atmosphere. A second burning phase is then initiated at apogee to inject the vehicle into an elliptic transfer orbit whose perigee is defined by the second burning phase cut-off point and whose apogee radius equals that of the desired final orbit. Final injection occurs near apogee of the transfer ellipse. This latter technique will see greater use than the conventional elliptic ascent in spite of the re-ignition requirements at altitude, and is currently proposed for Atlas-Agena launchings.

Launch Procedure

The countdown marks the end of a seemingly endless series of tests, checks and rechecks and of the many other problems associated with the launching of a space vehicle. The countdown has its beginning anywhere from several hours to several days prior to launch depending on the complexity of the vehicle and associated instrumentation. It is imperative to the over-all success of a mission that every subsystem function properly

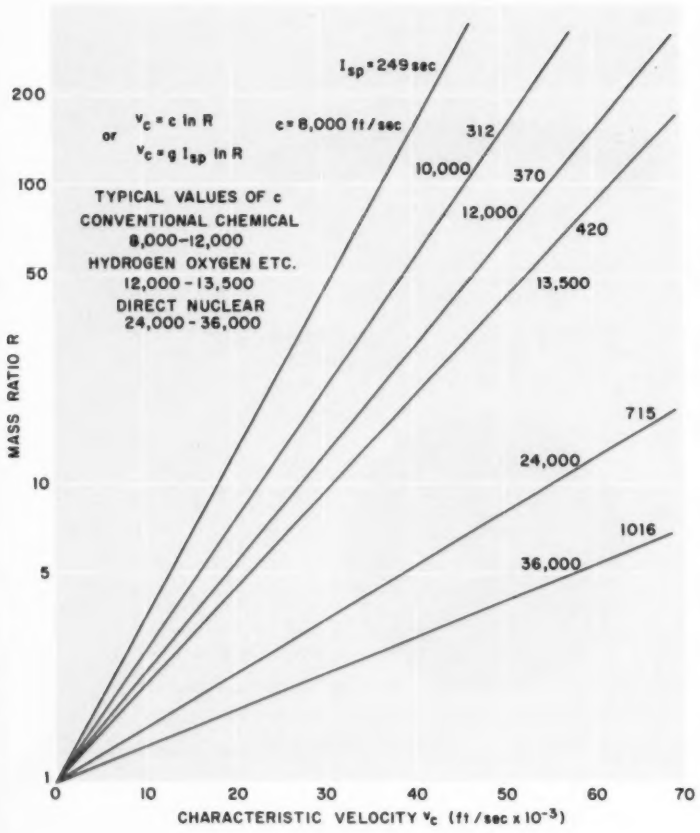

Figure 8. Characteristic velocity vs. mass ratio and exhaust velocity

throughout the flight and for this reason must be checked out just prior to launch.

Within the last few hours, the tanks are pressurized with an inert gas to support the vehicle and its payload, and the gantry supports are removed. The propellants are then pumped into the tanks against this pressure, and after this fueling operation is completed, the vehicle is ready for launch. With cryogenic propellants, there is usually some maximum allowable time between the fueling operation and lift-off because of the loss of fuel due to boil-off and the problems associated with maintaining components at low temperatures for long periods of time.

At ignition, the pumps are started and propellant flows into the engine where it is ignited by a pyrotechnic device. The vehicle is usually clamped to the launch pad until thrust builds up to some specified value in excess of the vehicle weight. Just prior to releasing the clamping devices, the guidance system is uncaged (if inertial guidance is used) and the umbilical connections to the vehicle are severed. Lift-off occurs when the clamps clear the vehicle and it leaves the pad with an acceleration of some 0.5 to 2 g's (depending on the vehicle's characteristics), and continues along the precomputed reference trajectory.

Range Safety

During the powered phase of the ascent trajectory, the range safety officer may override all commands to the vehicle through the medium of the abort switch. In the event that the vehicle suffers mechanical failure or deviates too far from its precomputed trajectory the safety officer is responsible for destroying the vehicle before it leaves the confines of the missile range. When the abort signal is received by the vehicle, strips of primer cord encircling the propellant tanks are detonated, rupturing the tanks and destroying the vehicle.

In the case of manned flight, an abort becomes more complex since the environmental capsule must be free of the missile prior to the detonation. Current systems utilize small rockets to thrust the capsule away from the vehicle a few seconds before the missile is destroyed. This may appear remarkably simple at first; however, there are certain periods during which the manned capsule would undergo destructive entry into the atmosphere if the powered phase were terminated. In the case of mechanical failure, there is little that the safety officer can do; however, for flight path deviations, it may be possible to alter the trajectory prior to abort and allow for safe atmospheric entry. The problems encountered during atmospheric entry will be treated in a forthcoming article of this series.

Vehicle Capability

For convenience, the capability of a rocket vehicle is expressed either in terms of its orbital payload capacity or its ideal characteristic velocity. The payload is the useful mass that the vehicle can place into an ideal orbit about the Earth at some specified radius. The inert structural mass of the launching vehicle's final stage is not considered payload, even though this goes into orbit.

The characteristic velocity expresses the velocity that a rocket vehicle would attain if it burned all its fuel under ideal conditions, that is, without suffering aerodynamic or gravitational losses. In this case (see Equation 3), since R_i is dependent on the mass of the useful payload, the velocity capability decreases with increasing payload. This is easily demonstrated for a single-stage vehicle (see Figure 8), where the mass ratio R is expressed by

$$R = \frac{m_o}{m_s + m_p} = \frac{m_o}{m_o - \dot{m}\tau} .$$

In this expression m_s is the inert structural mass of the vehicle and m_p is the useful payload. It must be kept in mind that the final weight of a vehicle consists of both structure and payload; and that it is this total weight

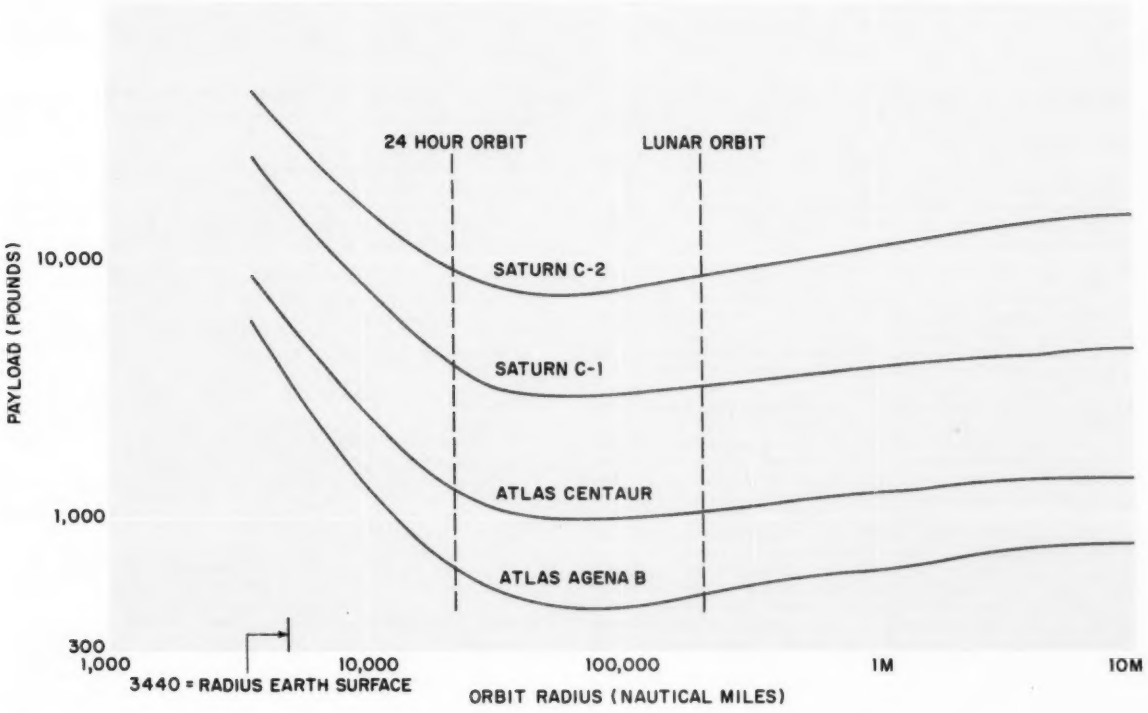

Figure 9. Typical satellite launch trajectories

that is accelerated to the characteristic velocity. For a multi-stage vehicle, the final weight consists of the inert weight of the last or upper stage plus the useful payload.

In space, where there is no atmosphere and where gravity losses are small, mission requirements and vehicle capability are always expressed in terms of characteristic velocity. A satellite launching vehicle, on the other hand, experiences high gravitational and aerodynamic losses. It is, therefore, simpler in this case to take a given vehicle and determine the maximum payload that it can place in orbit about the Earth (e.g. at a 300 mile altitude). This may then be used as a measure of its capability since the velocity requirement necessary for this maneuver varies between 26,000 ft/sec and 32,000 ft/sec depending on the physical characteristics of the vehicle which determine the extent of the drag and gravity losses.

The approximate orbital capabilities of several vehicles utilizing a ballistic ascent for the low orbits (under 500 nautical miles altitude) and dual-burn elliptic ascent for the high orbits are presented in Figure 9. The escape capability of a given vehicle is equivalent to its orbital capability at an infinite radius since orbital velocity is zero at infinity, and, for practical purposes, orbital capability at 10^7 nautical miles essentially represents escape capability. It is of interest to note that the orbital payload capability experiences a minimum near orbital radii of 55,000 nautical miles. The existence of this minimum will be discussed in detail in a forthcoming paper on interorbital transfer.

Summary

The basic problem associated with the launch phase of a space vehicle is unlike that encountered in all other phases of technology except ballistics. The rocket engines are not expected to run continuously during the flight of a vehicle, they simply impart a velocity to the vehicle so that its subsequent motion under the gravitational forces of the Earth (or any other parent body) satisfies the desired end conditions of the mission. To launch a satellite, the rocket engines must impart to the vehicle a velocity so that it coasts up to the desired altitude where further thrusting by the engines injects the vehicle into the desired orbit.

The velocities required for space operations are so great that their attainment by known means represents a major effort as is apparent by the scope of the current space program. The motion of a vehicle in deep space and the problems associated with planet fall (atmospheric entry and landing) will be discussed in subsequent papers of this series on astronautics. ■

PATENTS

ABSTRACTS OF RAYTHEON PATENTS issued during May and June, 1961. The following are abstracts of the technical content of the patents and do not necessarily reflect the scope of coverage being claimed in the patents. Copies of the patents may be obtained through Raytheon's divisional libraries.

JOHN SPANOS, "Electrical Connections to Semiconductor Bodies," Patent No. 2,982,893

This patent relates to a transistor in which a Kovar base tab is attached to the base region through a nickel plating applied to the Kovar tab.

ROBERT A. FRYKLUND, "Echo-Ranging System," Patent No. 2,982,940

This patent relates to a depth sounder system for underwater echo-ranging, and utilizes a variable delay means in the keying circuit to provide an expanded sweep for the echoing system. The delayed output pulse combined with a recording stylus, which may be driven at several selected speeds, provides selected expanded sweeps.

FRITZ A. GROSS, "Radar System for Producing a Remote Plan Position Indication," Patent No. 2,982,954

This patent relates to a system for transmitting radar information to a remote indicator station by a radar relay link, such as presently used with airport surveillance radar. The peak amplitude of certain of the pulses, such as the radar outgoing pulse sync signals, are modulated with azimuth information. The sync pulses are preferably transmitted in opposite polarity to the video pulses.

WILLIAM R. MERCER, "Signal Receiver," Patent No. 2,983,814

This patent relates to a receiver circuit which improves signal to noise ratio by frequency modulating an input signal, frequency or phase demodulating the signal and comparing the phase of the demodulator output with the modulating signal.

ALBERT D. LaRUE, EDWARD T. DOWNING, "Magnetron Electrode Structure," Patent No. 2,983,843

This patent relates to a hybrid magnetron anode in which a first group of anode vanes are used to define the resonant cavities and a second group of smaller vane segments are radially spaced about the cathode. This structure provides a large number of anodes and a relatively small number of resonant cavities to provide a high frequency device in which reasonable dimensions can be maintained for the anode and cathode structure while at the same time reducing mode separation and tuning problems ordinarily introduced as the number of resonant cavities is increased.

JOHN R. WILLIAMS, "Semiconductor Assembly Structure," Patent No. 2,983,853

This patent relates to a semiconductor structure wherein the semiconductive chip is mounted upon and bonded to a material which has substantially the same coefficient of thermal expansion as the semiconductor body. The external conducting leads extend through holes in the mounting means.

EDWARD C. DENCH, "Magnetron Oscillators," Patent No. 2,984,763

This patent relates to a non-re-entrant strapped anode delay line having a variable frequency responsive load coupled to one end of the delay line. Adjustment of the impedance of the load and the anode voltage may be coordinated to provide efficient operation over a wide frequency band.

WILLIAM C. BROWN, "Electron Discharge Devices of the Magnetron Type," Patent No. 2,984,764

This patent relates to a group strapped magnetron in which the group straps form a two-element transmission line a multiple of half wavelengths long connected between corresponding points on non-adjacent anode cavities. This type of structure reduces the phase shift between successive cavities.

GERSHON J. WHEELER, "Coaxial Switches and Power Dividers," Patent No. 2,984,797

This patent relates to a coaxial switch and power divider constructed of a plurality of sections of a quarter wavelength coaxial line forming four terminals. Short sections of coaxial line with ganged shorting plungers are disposed between pairs of terminals, each of these sections being separated by quarter wavelength lines from each other and also from each of the adjacent terminals. This device is employed as a switch by simply moving the ganged plungers each a quarter wavelength and is employed as a power divider by moving the plungers less than a quarter wavelength.

ROBERT A. FRYKLUND, "Depth Indicating System," Patent No. 2,985,015

This patent relates to a pressure-controlled variable frequency oscillator for indicating the depth of a net used in fishing. Net depth is set by means of fish-depth information obtained from a separate depth sounder. The cables towing the net are used as a transmission line for the net-depth signals.

JOHN F. AHEARN, LOUIS F. KILHAM, JR., "Electrical Cooling System," Patent No. 2,985,707

This patent relates to a system for cooling a piece of electrical apparatus such as a laminated transformer. The apparatus is immersed in an inert liquid, such as a fluorochemical, within a hermetically sealed case so that a portion of the apparatus and a portion of capillary material on the apparatus are immersed in the liquid. By capillary action, the liquid rises to the internal portions of the transformer over a dual path, one through the capillary material, and the other through the laminations themselves. The liquid is evaporated by absorption of the heat generated by the transformer, and condensed on the interior of the case returning to the liquid reservoir by gravity.

WILLIAM L. HATTON, "Slicing Circuit," Patent No. 2,985,836

This patent relates to tube and semiconductor versions of a slicing circuit in which a portion of filtered rectified voltage is impressed upon a gating amplifier stage having an output which biases a succeeding diode. Upon conduction of the diode, the input pulse is gated through to an amplifying stage which is biased to cut off when the voltage of the gated pulse exceeds a predetermined level. By this arrangement, only that portion of the pulse lying between the voltage at the gating stage and the voltage on the input of the amplifying stage is reproduced in the output of the circuit.

HENRY ZUCKER, "Electron Beam Convergence System," Patent No. 2,987,646

This patent relates to a particular type of electron beam convergence system for use in colored television. An integrator circuit produces a sawtooth wave which is then applied to parallel adjustable networks to produce parabolic waves. The parabolic waves are utilized to excite parallel auxiliary deflection coils to independently control the impinging angles of the three electron gun beams.

EARL J. SHELTON, JR., "Dielectric Windows," Patent No. 2,990,526

This patent relates to a dielectric window for use in transmission lines such as magnetron outputs in which the window is provided with a plurality of spaced tubular ducts arranged perpendicular to the electric lines of waves propagating through the window. Cooling fluid may be circulated through the ducts.

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PAPERS & PUBLICATIONS

All papers which have been presented at scientific meetings and published in technical journals are being listed in this section of ELECTRONIC PROGRESS. In order to ensure completeness, authors are requested to advise the Secretary, Technical Publications Panel (Lexington X240) when papers are accepted for presentation and publication.

Papers Presented at Scientific Meetings

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M. H. REISS, W. COVINGTON, Missile and Space Division, "Descent Guidance of a High Orbital Satellite." F. W. NESLINE, JR., M. FRAZIER, Missile and Space Division, "Mosaic, A New Type of Ballistic Missile Guidance System."

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Direct Solar Power Conversion for Space Vehicles ..... *R. C. Barbera, D. L. Dayton*
Stabilization ..... *R. E. Lang*

NUMBER 2 (SEPTEMBER-OCTOBER 1960)
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RAYTHEON LASER includes a Linde ruby rod* and a xenon flash tube with trigger output circuit. Complete equipment (right) comprises head, power supply, cables and remote control switch.

*Product of Linde Company, Division of Union Carbide Corporation

Raytheon ruby laser now available for laboratory investigations

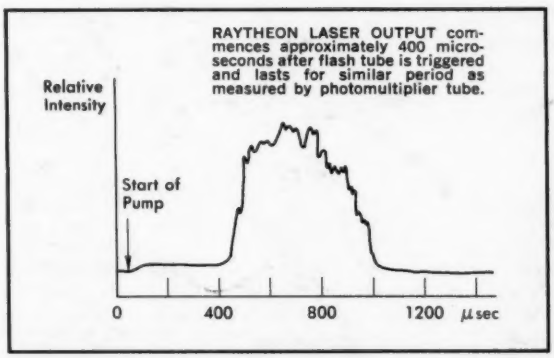
Complete equipment as shown is ready for use and priced at $5,850.

Raytheon's low-cost pulsed ruby laser complete with power supply is stocked for immediate delivery.

This new laboratory set-up is similar to the one recently exhibited at technical sessions and described in national scientific journals. The $5,850 price is possible because of an improved Raytheon optical design that permits laser action to be obtained with approximately one-tenth the flash tube energy previously required.

The laser head is constructed for convenient interchangeability of ruby rods and replacement of flash tube. The heavy-duty power supply is designed to permit precise adjustment of flash tube firing voltage for investigation of laser action at various power levels.

For complete technical proposal LTP-100, write to Special Microwave Devices Operation, Raytheon Company, Waltham Industrial Park, Waltham 54, Massachusetts.


RAYTHEON LASER OUTPUT commences approximately 400 microseconds after flash tube is triggered and lasts for similar period as measured by photomultiplier tube.
Relative Intensity
Start of Pump
0
400
800
1200
μsec

RAYTHEON COMPANY

MICROWAVE AND POWER TUBE DIVISION

RAYTHEON